Lessons Learned from MOVES and SMOKE Modeling

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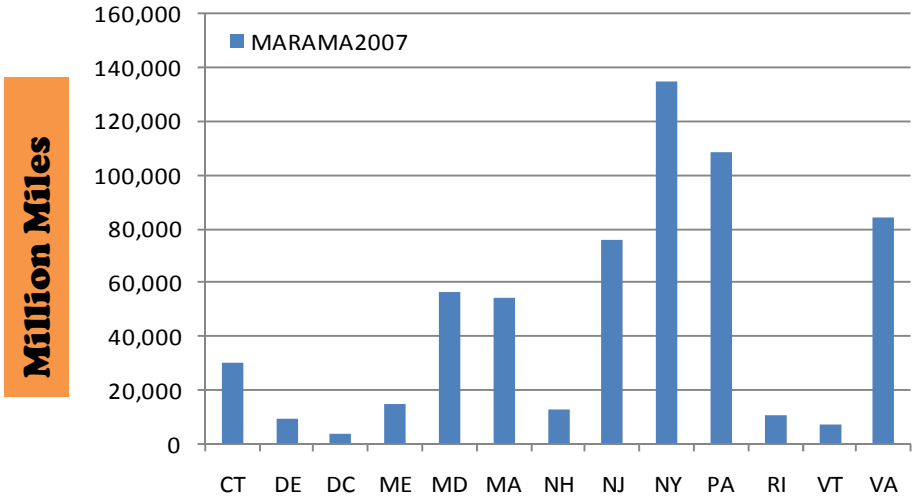
Presentation Overview

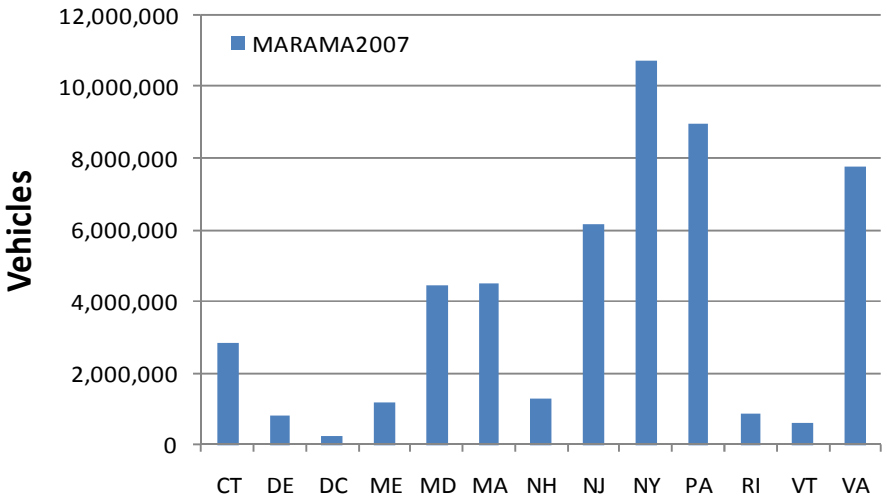
- Background
- SMOKE-MOVES Modeling System
- Spatial and Temporal Resolutions
- Development Timeline
- Uncertainties
- Recommendations
- Acknowledgments

Background – VMT, NOx and VOCs by states

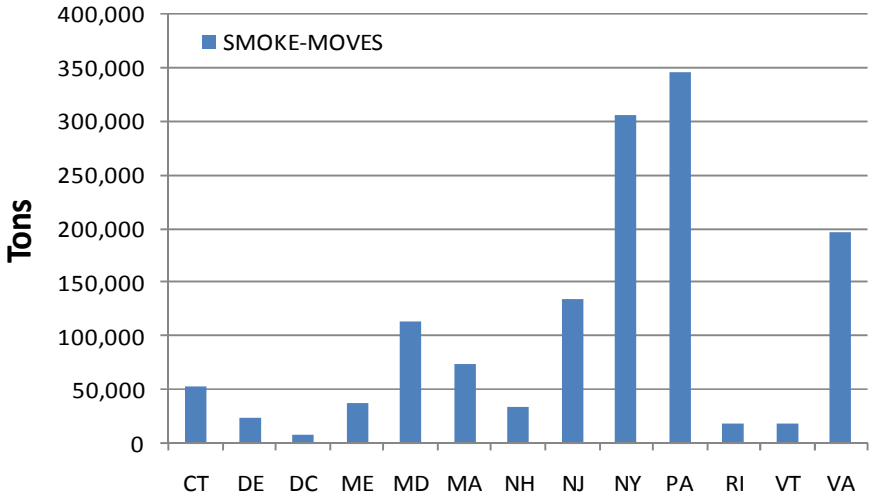
Mobile Source 2007 Annual VMT State Totals



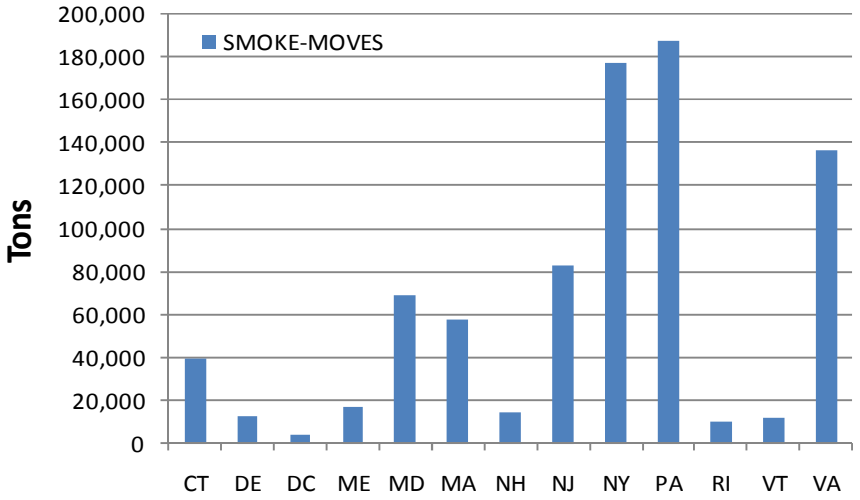
Mobile Source 2007 Annual VPOP State Totals



Mobile Source NOx State Totals, January - December 2007



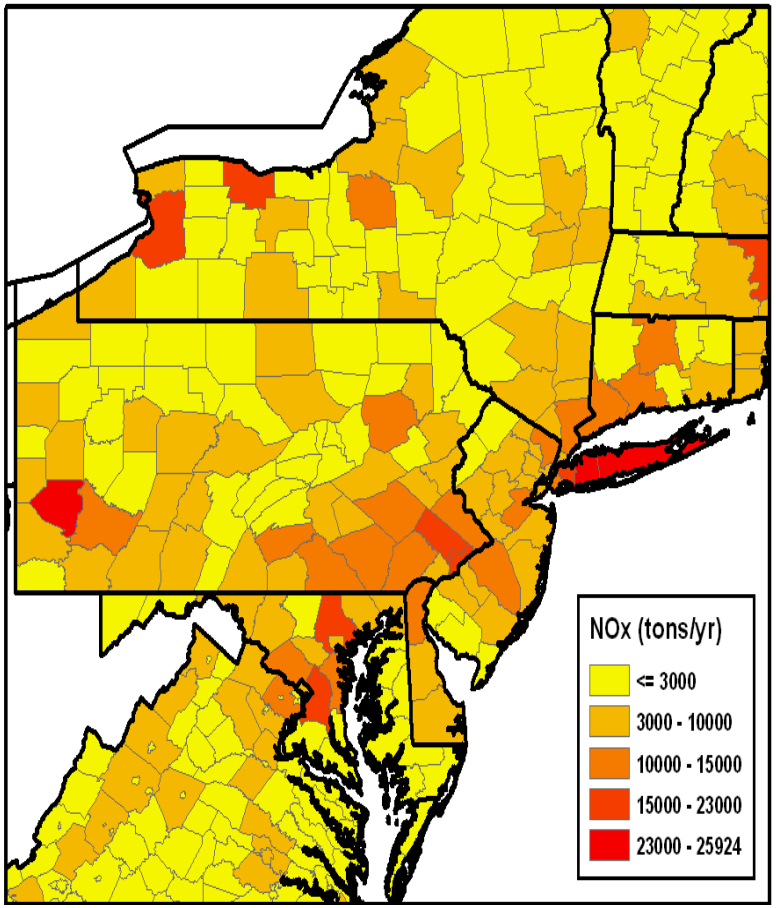
Mobile Source VOC State Totals, January - December 2007



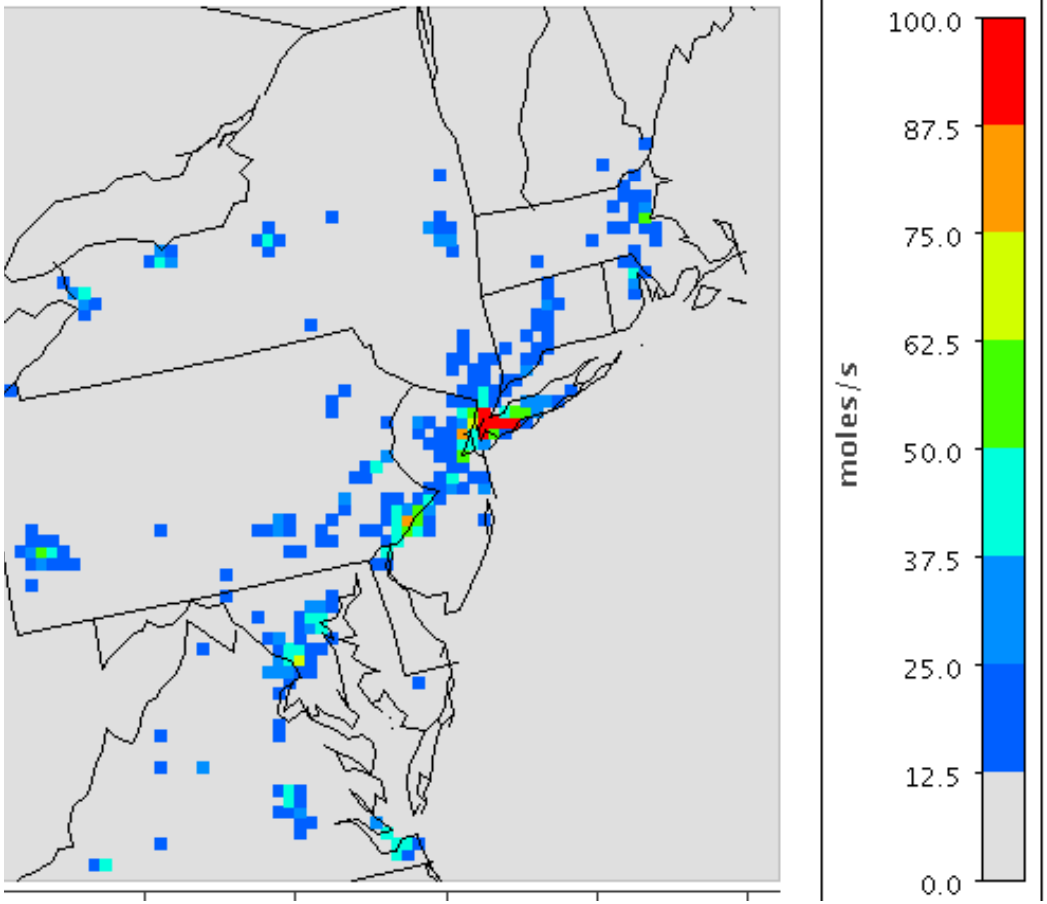
Background

spatial distributions of mobile NOx and CO

NOx in MANEVU+VA
annual emissions



CO in MANEVU+VA
7pm on 08/03/2007



Background

MOVES can be run in two modes:

Inventory mode	Emission rate mode
county scale	regional scale
monthly averaged temperature	hourly temperature
non-modeling inventory	modeling inventory
conformity analysis	air quality modeling

county level by month

grid cell by hour

-- Emission rate mode is often referred as lookup table mode (**focus of this presentation**);
-- Due to SMOKE input requirement (VMT/VPOP by SCC), both **inventory mode** and **emission rate mode** are needed to generate lookup tables for a regional modeling inventory

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SMOKE-MOVES Modeling System

For developing regional emission inventory,
the modeling system consists of 3 components:

- **MOVES**

  MOVES2010a (released in September 2010)

  updated from MOVES2010 (released in December 2009)

- **SMOKE-MOVES Integration Tool**

  undergone many version changes;

  most recent version released in September 2011

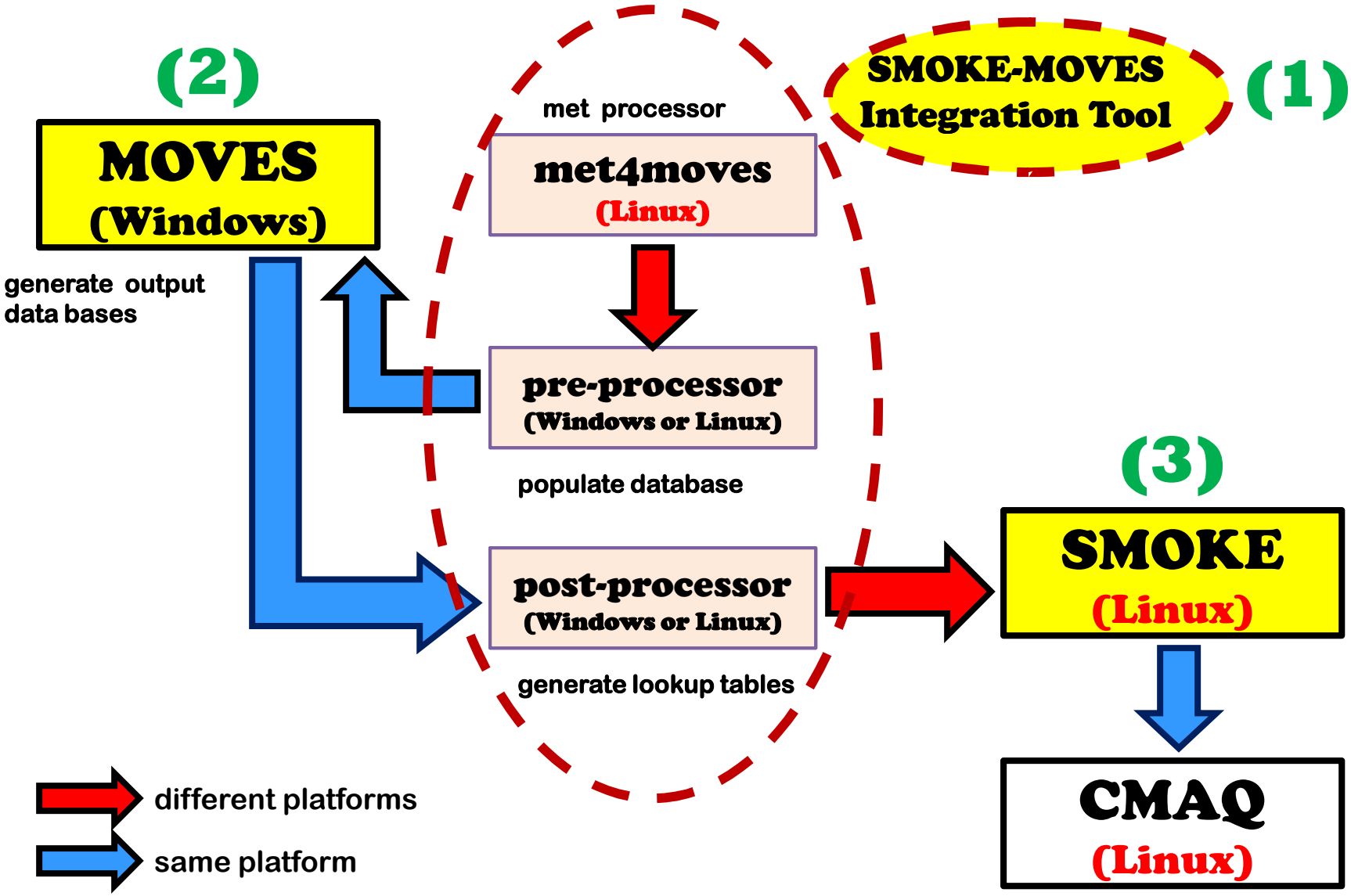
- **SMOKE**

  undergone many version changes;

  most recent version (v3.0) released in September 2011

SMOKE-MOVES System

Processing Flowchart



Files transfer across platforms is necessary if MOVES is run on Windows

Run Time

MOVES

Model (1 county, 1 month)	MOVES2010	MOVES2010a
inventory mode	1 – 2 hours	1 hours
lookup table mode	3 – 5 days	25 hours
cloud computing (3 nodes)	N/A	14 hours

-- MOVES run time comparison is based on one county and one simulated month;
-- Inventory mode often run for individual county;
-- On the other hand, emission rate mode often run for representative county;
-- Virginia has 134 counties, making it even more difficult to run MOVES.

cloud computing (distributed processing):
take advantage of multiple MOVES installed in multiple machines to reduce run time

MOVES Run Time -- example

Lookup Table Mode for MANEVU

- **49 MANEVU representative counties, 2 fuel months**

MOVES 2010: 4 days (per county per month) * 49 * 2 = **392** days

MOVES 2010a: 25 hrs (per county per month) * 49 * 2 = **102** days

Cloud computing: 14 hrs (per county per month) * 49 * 2 = **57** days

Adding an extra fuel month increases run time by 50 days

- **VA conducts MOVES runs on Linux cluster with cloud computing capability**

- **OAQPS and consulting companies run MOVES on Linux**

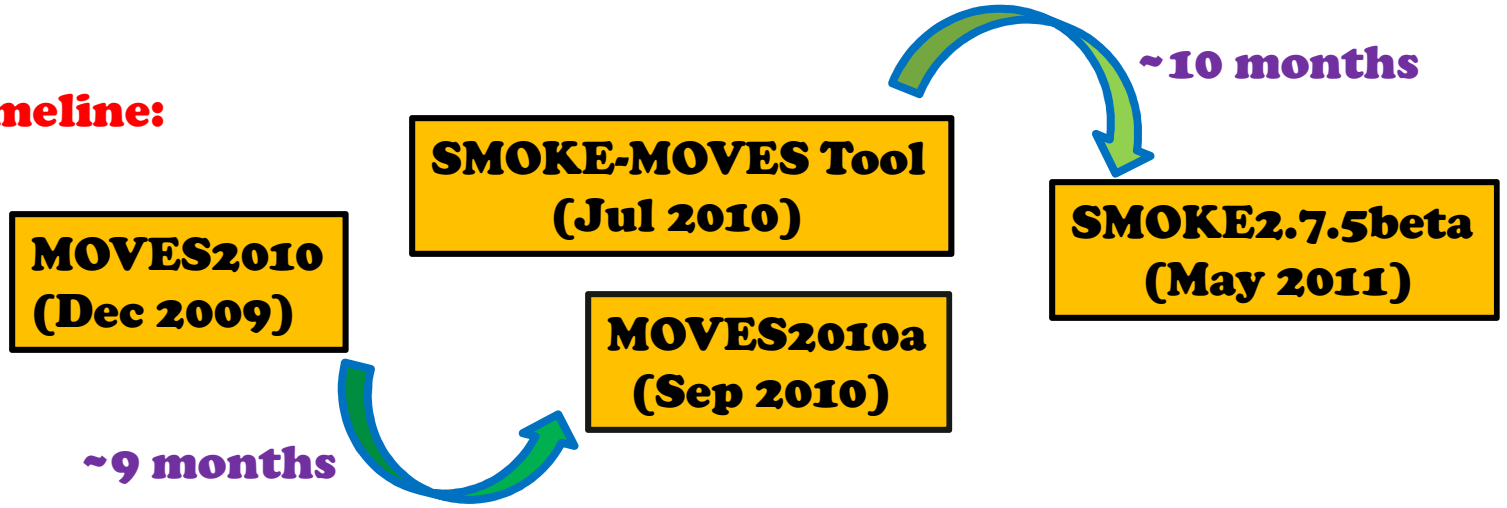
Run Time

SMOKE

Model	SMOKE v2.7	SMOKE v2.7.5 beta	SMOKE v3.0
1 rep county, 1 episode month	6 hours	11 minutes	8.6 minutes
49 rep counties (MANEVU), 12 episode months (annual)	150 days	4.5 days	3.5 days

-- SMOKE run time assumes only one computer being used;
-- Even when work was split among modeling centers, SMOKEv2.7 still took two weeks to complete MANEVU+VA region;
-- SMOKE2.5.7b (or thereafter) has reduced run time considerably.

Timeline:



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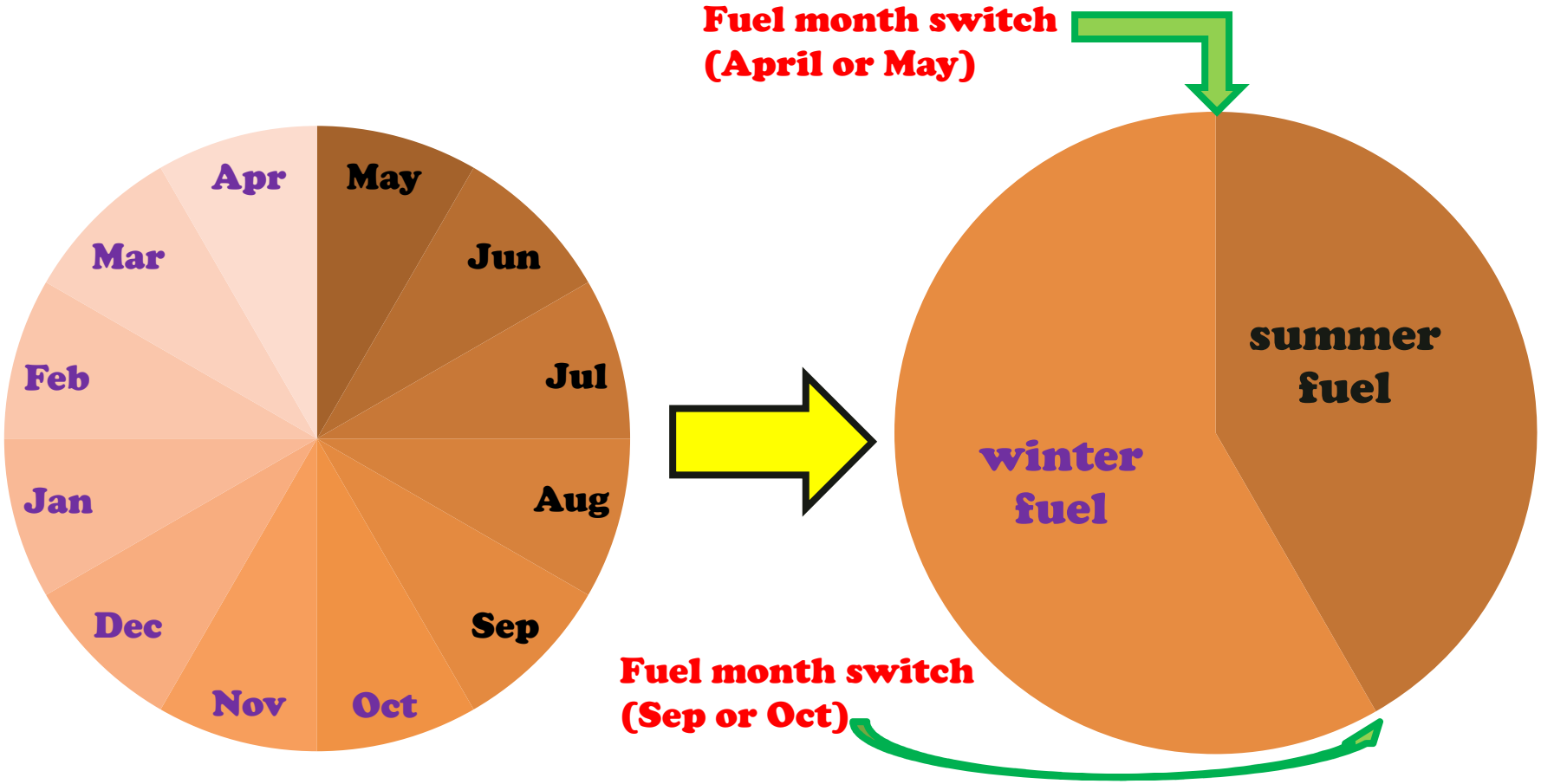
Resolutions in Time/Space

To reduce excessively long run time, MOVES lookup table mode is simplified in time and space resolutions:

- **Fuel Month – time**
- **Representative County – space**
- **Temperature – grid cells in hours**

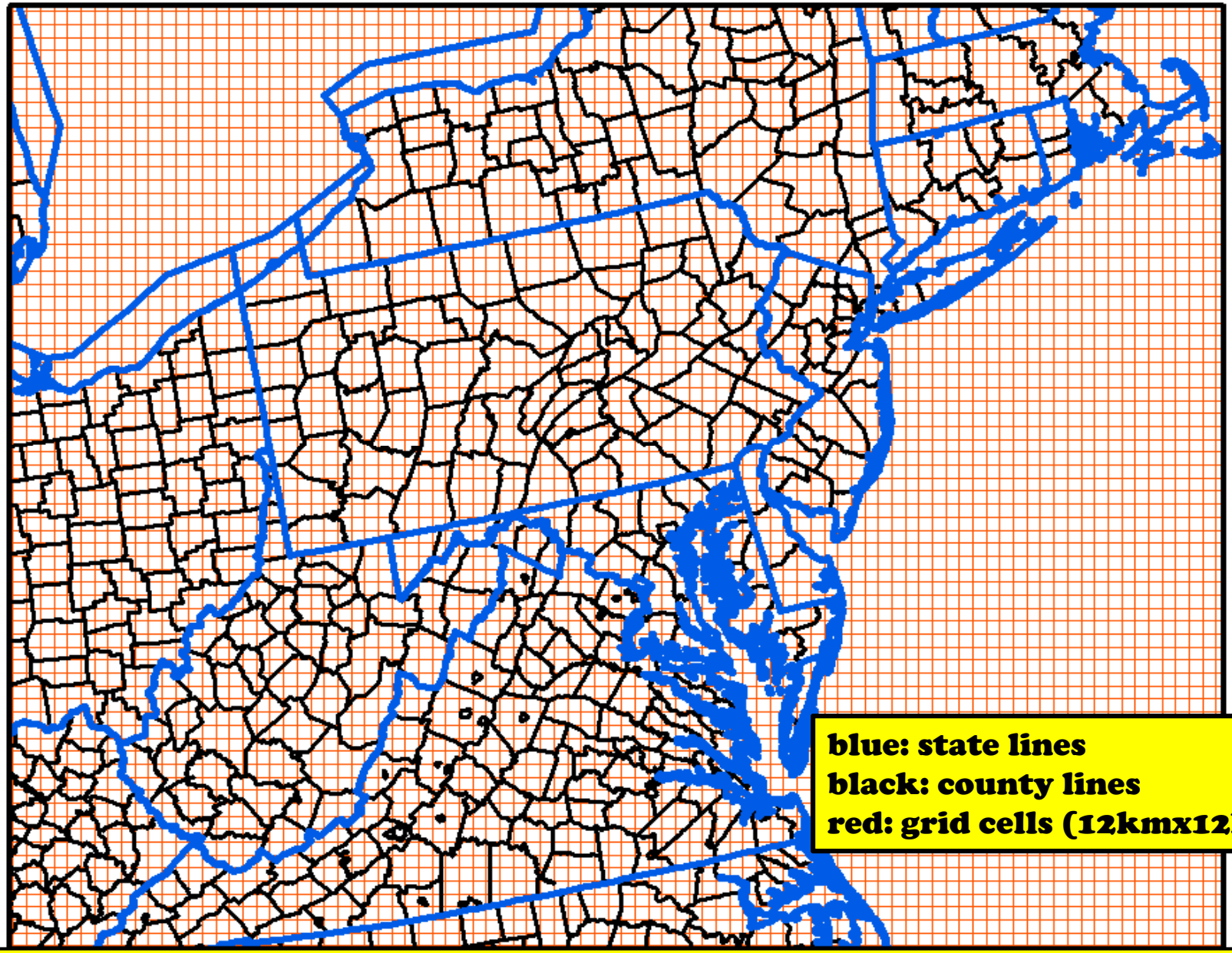
- Temperature effect is the driving force to run MOVES in lookup table mode;
- Fuel month and representative county are for reducing run time.

Resolution in Time



-- Twelve-monthly fuels are grouped in MOVES modeling into two groups: summer and winter fuels;
-- May to September is assumed for summer fuels, and October to April for winter fuels;
-- All modeling centers in the US have used the two fuel month approach;
-- Resolution of two fuel months may be too coarse.

Resolution in Space



Each county is represented by many grid cells; Resolution in county level is too coarse

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Development Timeline
Summary

- **December 2009**

  MOVES2010 released

- **July 2010**

  SMOKE-MOVES Integration Tool released

- **September 2010**

  MOVES2010a released

- **September 2010 – September 2011**

  Over a dozen issues addressed and enhancements made to all 3 components (MOVES, Integration Tool, and SMOKE)

Development Timeline -- Details

(releases, problems, updates, and bugs/fixes)

Mon/Year	Event	Models	Notes
(1) 12/2009	MOVES2010 released	MOVES	excessive long run time for lookup mode
(2) 07/2010	SMOKE-MOVES released	Integration Tool	Integration Tools always released in conjunction with SMOKE
(3) 09/2010	MOVES2010a released	MOVES	combining 2010a and Integration Tool reduced run time significantly
(4) 09/2010	bugs with out-of-T range and non-consecutive fuel months	met4moves	beta version released, tested, and fixed
(5) 10/2010	redundant road types in run spec, slowing down MOVES	MOVES	road types removed in run spec, run time improved drastically (5 days -> 1 day)
(6) 12/2010	Inadequate (state level only) SMOKE reports	SMOKE	duplicate runs avoided; detailed SIP quality reports by county and by SCC
(7) 01/2011	SMOKE enhancements	Integration Tool and SMOKE	aggregation of processes, SMOKE auxiliary files, run time reduced
(8) 02/2011	HONO dilemma (NO/NO2/HONO split)	MOVES, integration tool, and SMOKE	either NOx or NO/NO2 splits is fine; HONO included in lookup tables eventually
(9) 02/2011	abnormal rates at warmest T bin in lookup tables	Integration Tool	RD lookup tables re-generated by correcting error in post-processing script
(10) 02/2011	no VOC in SMOKE reports	SMOKE	fake species VOC_INV work-around added
(11) 03/2011	unexpected missing roadtypes in representative counties	Integration Tool	missing rates derived from similar road types in post-processing script

for chronological records

Development Timeline -- Details

(releases, problems, updates, and bugs/fixes)

Mon/Year	Event	Models	Notes
(12) 03/2011	missing or incorrect extended idle rates	Integration Tool	an external MySQL database with national idle rates released by EPA
(13) 04/2011	VMT/VPOP not conserved in MOVES	MOVES	**no resolution**
(14) 05/2011	**SMOKE2.7.5b beta testing**	SMOKE	run time for on-road reduced significantly (150 days->4.5 days for 49 MANEVU rep counties)
(15) 06/2011	VOCs sudden drop/jump when fuel month switches	SMOKE	**no resolution**
(16) 06/2011	identical rates across all T bins for missing road-types	Integration Tool	fixed query criteria used in the road-types Replacements
(17) 07/2011	RPP sector cannot handle finer T (i.e. 5C) increments	met4moves	beta version (SMOKEv3.0) released for testing
(18) 07/2011	extended idle database mishap (two versions)	Integration Tool	OTC states obtained correct database; no change needed
(19) 08/2011	zero rates in lookup tables for leap year (i.e., 2020)	MOVES	problem fixed by using two blocks of monthvmtfractions with IsLeapYear both Y/N
(20) 09/2011	**SMOKE v3.0 released**	Integration Tool, SMOKE	included all updates, fixed, improvements, etc.
(21) 11/2011	MOVES data exchange among RPOs	SMOKE	**work in progress**
(22) 11/2011	speed profiles in SMOKE	SMOKE	**work in progress**

for chronological records

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Uncertainties

- Conservation of Activities
- Approach of Two Fuel Months
- Effect of Speed Profiles
- RPOs Inventory Merge
- Effect of Relative Humidity:

  cannot be simulated under current modeling framework

Conservation of Activities

violation of basic principle of conservation

inputs (VMT, VPOP) ≠ **outputs (VMT, VPOP)** → SMOKE

County/State	VMT (% change)	Loss/Gain	Notes
York, VA	minimal	gain	after adjustments
Fairfax, VA	0.01%	loss	no adjustment
Mercer, NJ	0.6%	gain	no adjustment

-- MOVES activity outputs are fed into SMOKE; ← **Important!**

-- None of the counties modeled conserves activities (either loss or gain);

-- Adjustments can be made to recover some VMT and VPOP losses;

-- for example, adding CNG will recover almost all loss of VPOP, but not loss of VMT;

-- Question: are the loss "real"? SMOKE loss is real, and if loss in inventory mode is real too, then emissions will be affected.

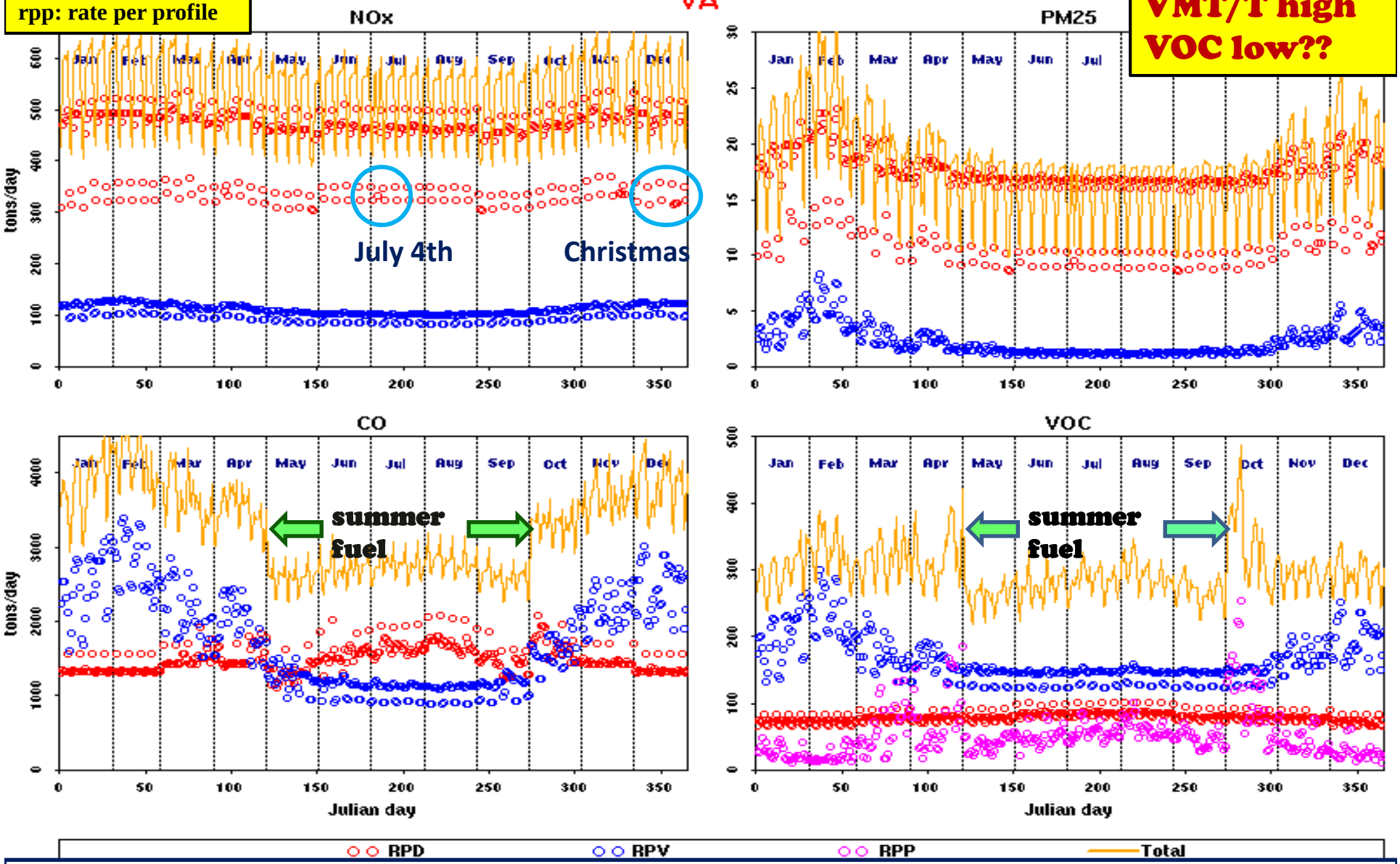
-- VMT loss/gain has not been resolved yet.

rpd: rate per distance
rpv: rate per vehicle
rpp: rate per profile

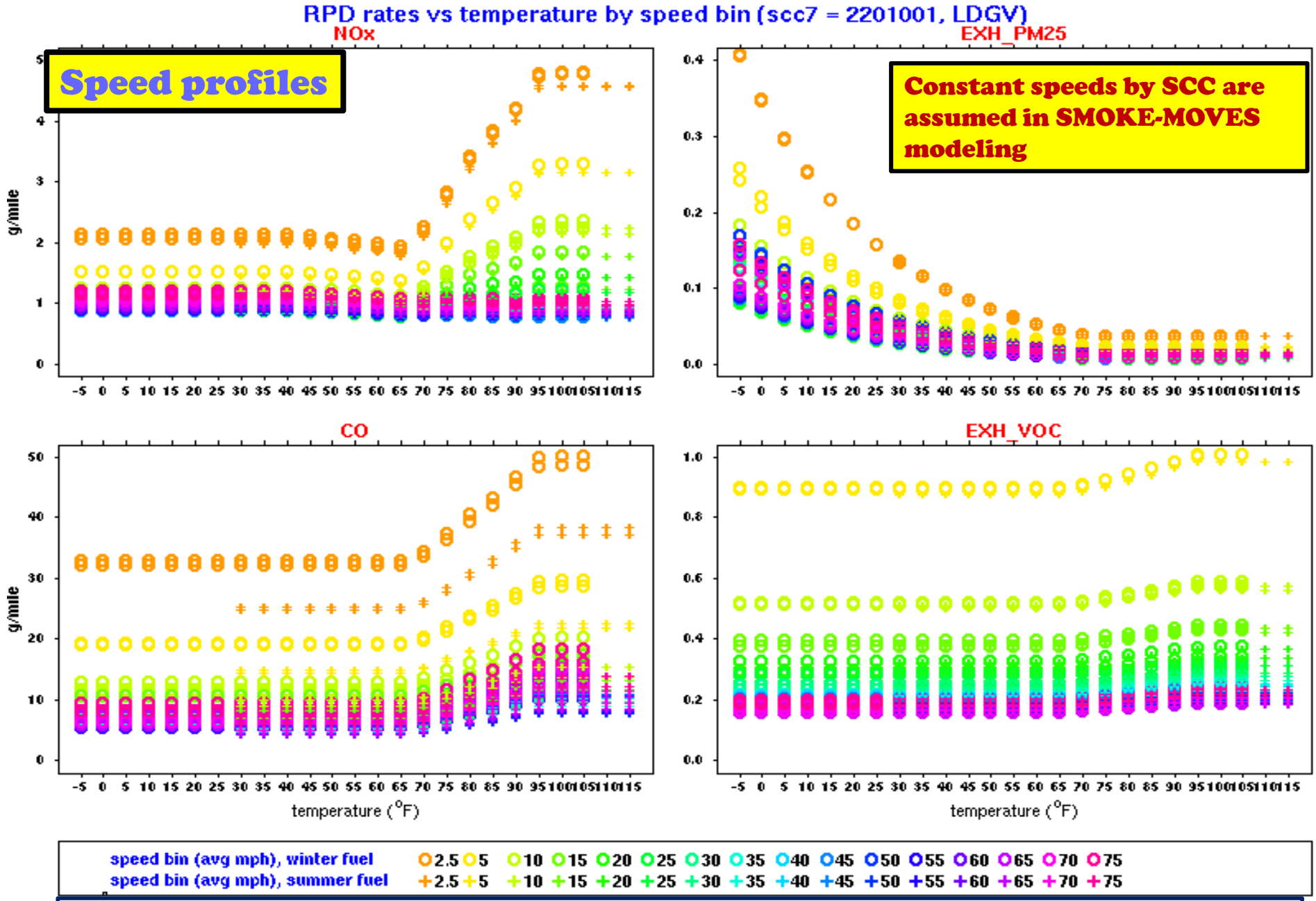
Approach of Two Fuel Months

VA

summer:
VMT/T high
VOC low??



-- For NOx and PM2.5, RPD dominates among the three sectors, accounting for >80% of the two pollutants.
-- By contrast, for CO and VOCs, RPV is the dominating sector, whereas RPP is the least contributor to VOCs among the three.
-- Usage of winter or summer fuel affects CO and VOCs, causing both to have sudden drop and jump in fuel transition months (May and October).
-- Emission rates for CO and VOCs are higher with winter fuel than with summer fuel.



-- LDGV releases more NOx and CO at higher temperatures, but emits more PM2.5 at lower temperatures.

-- **The lower the speed an LDGV travels, the higher the emissions for all pollutants.**

-- Winter and summer fuels affect CO only. Winter fuel has higher CO emission rates than summer fuel.

Modeling and Data Collection

balance between accuracy and data availability

Fuel Months

If modeling more than 2 fuel months:

(1) long run time expected

(2) most states have no monthly RVP data

Speed Profiles vs Constant Speed

SMOKE can handle 24-hr speed profiles:

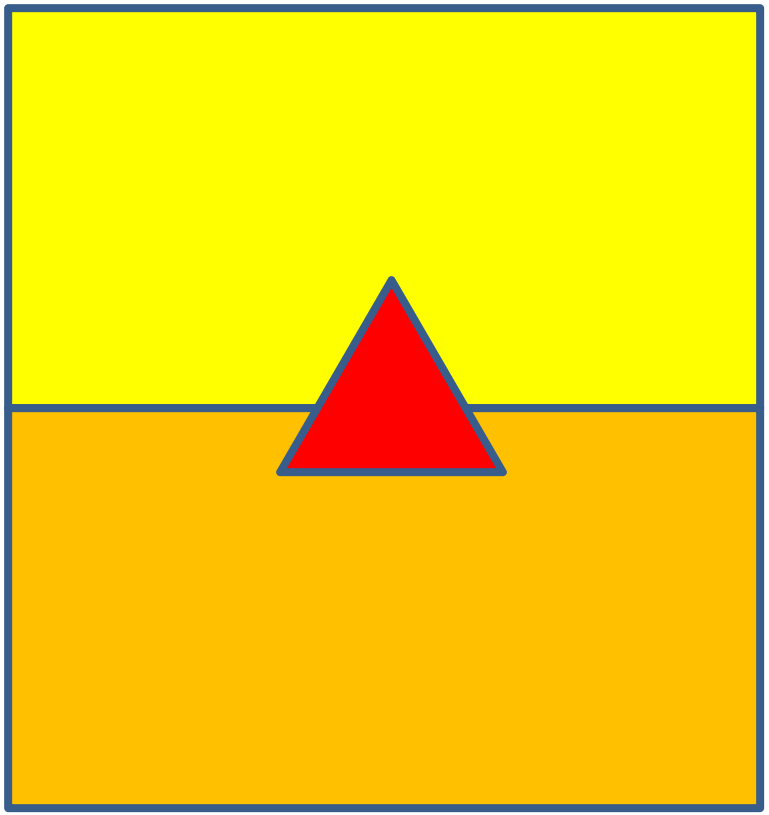
(1) field measurements by SCC needed

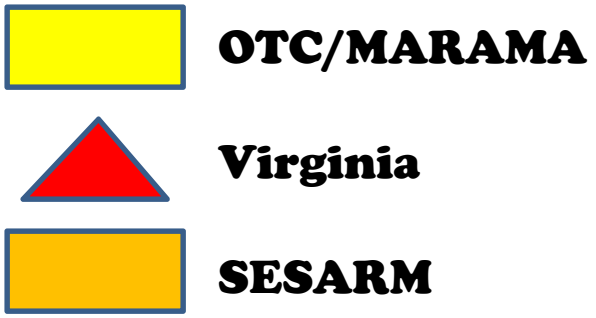
(2) run time/effects unknown

SCC = fuel types + vehicle types + road types

RPO Inventory Merge

Simplified Modeling Domain



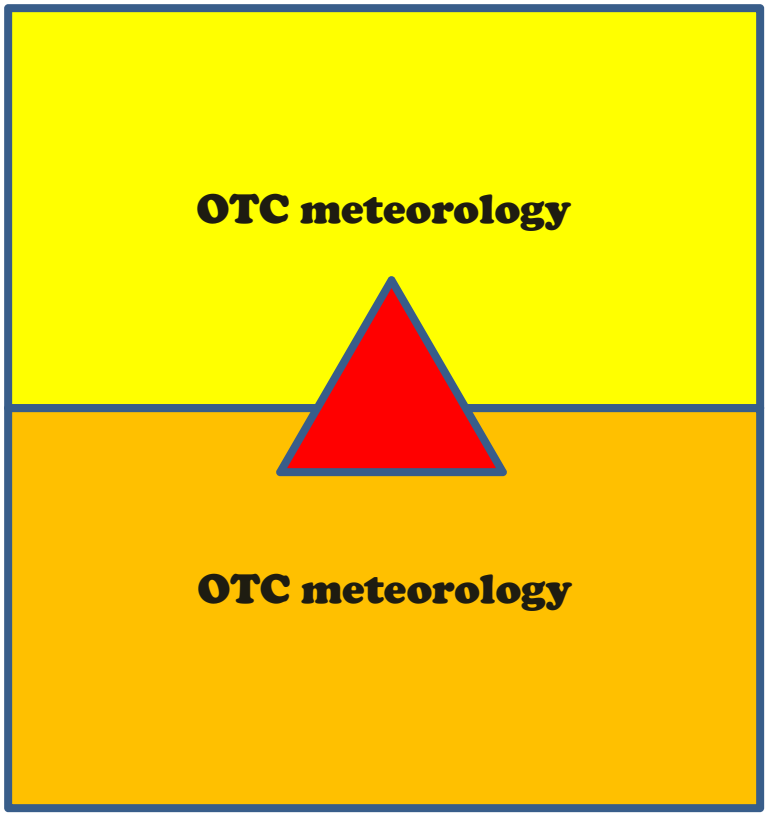


(1) Virginia is part of both OTC and SESARM;

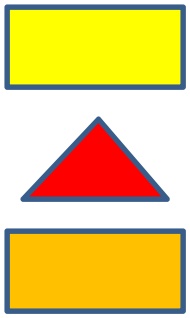
(2) Mobile emissions must be generated for all three regions for air quality modeling;

(3) In reality, emissions also include LADCO, CENRAP and MRPO.

RPO Inventory Merge (cont.)
Ideal Inventory – Option Four
consistent meteorology



From OTC's perspective:



Done

Done

To be generated

(1) Ideally, OTC would conduct MOVES runs using its own meteorology to generate emissions for SESARM region (in orange);

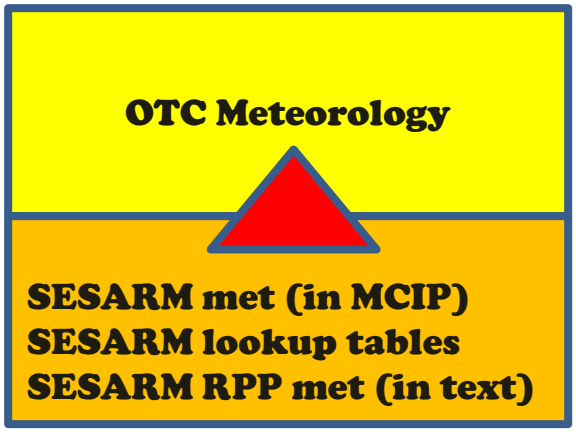
(2) Difficulty: No MOVES inputs;
Prohibitive in time/resources;

(3) Ideal inventory is what has been done in the past with MOBILE6 (and other source sectors). It is the option 4 listed in the proposal by Zac Adelman of UNC.

RPO Inventory Merge –Alternative Options

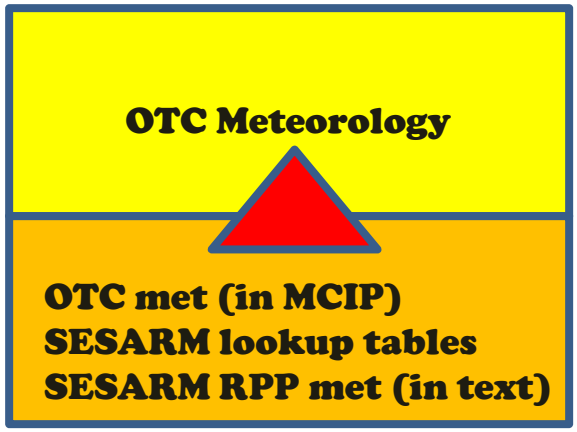
data exchange (OTC's perspective)

Option One



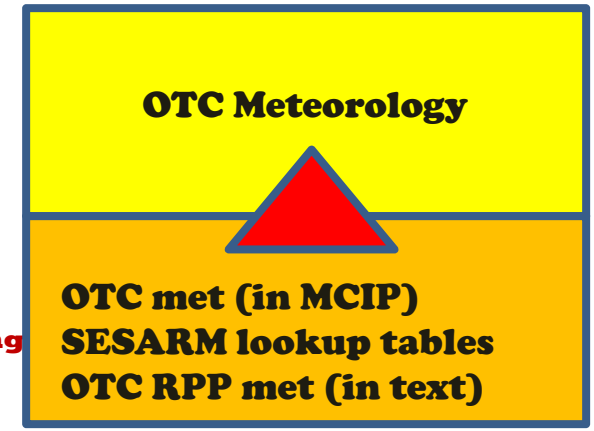
Use SESARM result directly

Option Two



SMOKE (but not MOVES) modeling needed

Option Three



SMOKE (but not MOVES) modeling needed

Option four

Ideal Inventory (previous page)

-- Alternatives involve exchanging lookup tables (and met data) between two RPOs to avoid time-consuming MOVES runs;
-- None of these options (even for option three) maintains meteorological consistency;
-- Option three looks to be - but is not - the ideal inventory because of inherent RH in the lookup tables received, although it is the closest;
-- OTC and SESARM domains have different regional coverage. Option one therefore needs domain transformation;
-- If viewed from SESARM's perspective, everything should be reversed.

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Recommendations

- **Develop/Release MOVES for Linux**
- **Modeling Guidance (by EPA):**
  - **a. conservation of activity**
  - **b. fuel months**
  - **c. CO and VOC profiles**
- **Systematic Sensitivity/Comparisons:**
  - **a. lookup mode vs inventory mode**
  - **b. RVP (Reid Vapor Pressure)**
  - **c. summer VMT/Temp both high but VOCs low??**
  - **d. speed profiles**
  - **e. annual VMT vs monthly VMT**

Recommendations (cont.)

- **More Research:**
  - a. evaluate MOVES against observations
  - b. lookup tables exchangeable?
- **Remaining Issues:**
  - relative humidity
- **Open/Constructive Communications:**
  - OTAQ (MOVES)
  - OAQPS (SMOKE-MOVES)
  - UNC (SMOKE)
  - RPOs (emission leads)
  - states and other end users

Acknowledgments

- MARAMA
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